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High-speed cinematographic evaluation of claw-ground contact patterns of lactating cows

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High-speed cinematographic evaluation of claw-ground contact pattern of lactating cows

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Abstract

To evaluate the manner in which a cow's claws make contact with the ground at the walk, the gait, and in particular the claw-ground contact pattern, were studied in 12 healthy, lactating dairy cows, using high-speed cinematography (500 frames/s) while the animals were walking on a treadmill. The results showed that the limbs were advanced around the contralateral limbs in a sigmoid curve. The feet contacted the ground with the foot axis and the tips of the claws rotated slightly outwards. In all cows the lateral claws contacted the ground before the medial claws in the hindlimbs, and in 10/12 cows in the forelimbs. The heel of the lateral claws was the region of initial contact with the ground in the hindlimbs of all cows and in the forelimbs in 9/12 cows. Lateral 'heel first' contact in the fore and hindlimbs appeared to be the normal gait pattern in these animals.

Compared with a previous study of heifers, lactating cows had a larger step width in the hindlimbs and a smaller step width in the forelimbs. These ground contact patterns offer an explanation for the predisposition to claw disorders of the lateral claw of the hindlimb. The results of this study reinforce the suggestion that soft floor surfaces should be provided for cattle to prevent mechanical injury to the claws.

Keywords: Dairy cows; Gait analysis; High-speed cinematography; Claw diseases

Introduction

Claw diseases in cattle most commonly occur in the lateral claws of the hindlimbs. If disease occurs in the forelimbs, the medial claws appear to be affected more frequently, although this predisposition is less clear-cut (Distl and Schmid, 1993; Leach et al., 1998). In standing cows, the lateral claws of the hindlimbs bore more weight than the medial claws (Prentice and Wright, 1971; Kehler and Gerwing, 2004; Van der Tol et al., 2002). Similarly, kinetic studies in cows have shown that the lateral claws sustain the majority of forces of the hindlimbs at the walk (Scott, 1988; Van der Tol et al., 2003). The vertical ground reaction forces (vGRF) were shown to be distributed about equally between the claws of the forelimbs (Van der Tol et al., 2003), although in other studies the peak pressures concentrated on the lateral claws (Carvalho et al., 2005), which contacted the ground first (Meyer et al., 2007). In vitro pressure measurements of post mortem hind claw specimens of cows revealed that stress is concentrated in the heels of the lateral claws (Zeiner et al., 2007). Thus biomechanical forces seem to be a risk factor for the development of claw horn lesions.

In large animal veterinary medicine, high-speed cinematography was first introduced in horses (Fredricson et al., 1980) and allows study of the details of locomotion because the time resolution exceeds that of the human eye. In cattle, high-speed cinematography (100 frames/s) was used to

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measure various joint angles during the walk (Herlin and Drevemo, 1997). These authors showed that some of the joint angle movements were affected by different housing regimes and that, in particular, cows kept in cubicles throughout the year had a restricted range of motion in the elbow and hock. Cows kept on pasture had steeper angulation of the fetlocks of the hindlimbs, which was thought to be the result of greater strength of the flexor tendons, muscles and ligaments attributable to physical exercise on pasture (Herlin and Drevemo, 1997). In these studies the animals walked on solid ground, however there are clear advantages in using a treadmill where multiple gait cycles can be evaluated under standardised conditions.

For gait studies on a treadmill, the animals must first become accustomed to the unusual walking conditions. The treadmill surface has to be non-skid and able to absorb shock. Experienced observers were unable to differentiate gait characteristics of horses on a treadmill from those on firm ground (Fredricson et al., 1983). However, gait patterns on a treadmill are specific and not identical to those on other ground (Buchner et al., 1994; Weishaupt et al., 2004). In a recent study, the ground contact patterns of the feet at the first half of the stance phase were analysed using high-speed cinematography (500 frames/s) in 18 non-lactating heifers (Meyer et al., 2007). In order to assess multiple consecutive stride cycles (Leach, 1993; van der Tol et al., 2003), the heifers were filmed while walking on a treadmill. At heel strike, the lateral claws contacted the ground 14 (standard deviation [SD] = 12) ms before ($P < 0.05$) the medial claws in the front and 24 (SD = 8) ms before the medial claws in the hindlimbs (Meyer, 2006). This 'lateral landing' was predominant and therefore considered to be normal in heifers (Meyer et al., 2007). Likewise, lateral landing occurred in the fore- and hindlimbs of the majority of horses examined at a trot using dynamic pressure measurements (van Heel et al., 2004).

The goal of the present study was to examine claw-ground contact patterns of lactating cows while walking on a treadmill using high-speed cinematography and compare these findings with those already obtained from non-lactating heifers.

Materials and methods

Lactating cows from five different farms with a mean age of 35 months (SD = 9 months) and a bodyweight of 586 kg (SD = 50 kg) were used in the study. There were six Swiss Braunvieh and six Swiss Holsteins (three of these were Red Holsteins). The cows were an average of 69 days (SD = 33 days) postpartum and yielding an average of 21 L of milk/day. Before entering the study, the cows were kept in tie stalls with regular, but not daily, exercise on a paddock in the winter and access to pasture in the summer. The animals were clinically healthy and had no signs of lameness. Because the claws were slightly overgrown, they were trimmed to achieve normal gait characteristics. At this time no signs of claw disease were detected.

Handling and treadmill training was conducted over 4 days and lasted 20 min/cow/day. The claws were trimmed on day 2 of the study, according to the principles of Toussaint Raven (1989). The cows were divided into groups of two or three for adaptation to the treadmill and the experimental setup. Filming and gait analysis were started after the gait of the cows had become regular and the animals were relaxed while walking on the treadmill. This occurred on day 4 in 10 cows and on day 5 in two cows. Measurements were made a minimum of 2 h and a maximum of 7 h after milking.

The speed of the treadmill (Mustang 2200, Graber AG) could be adjusted in 0.1 m/s increments and was set individually for each cow until it achieved regular walking characteristics. This was confirmed by the regularity of the stride patterns and the regularity of the vGRF curves. The position of each foot on the treadmill platform was calculated using trigonometry on the basis of angles determined with angular encoders as described by Weishaupt et al. (2002). The step width was defined as the transverse distance between the interdigital clefts of the feet (Fig. 1). The step width was determined at two moments of the stance phase, at heel strike (step width 1) and at push-off (step width 2).

Because no significant differences had been detected between the pattern of ground contact of the left and right limbs in the study using heifers (Meyer et al., 2007), only the left limbs of the cows were filmed. The animals were filmed after functional claw trimming while walking on a treadmill using high-speed cinematography (500 frames/s). A digital high-

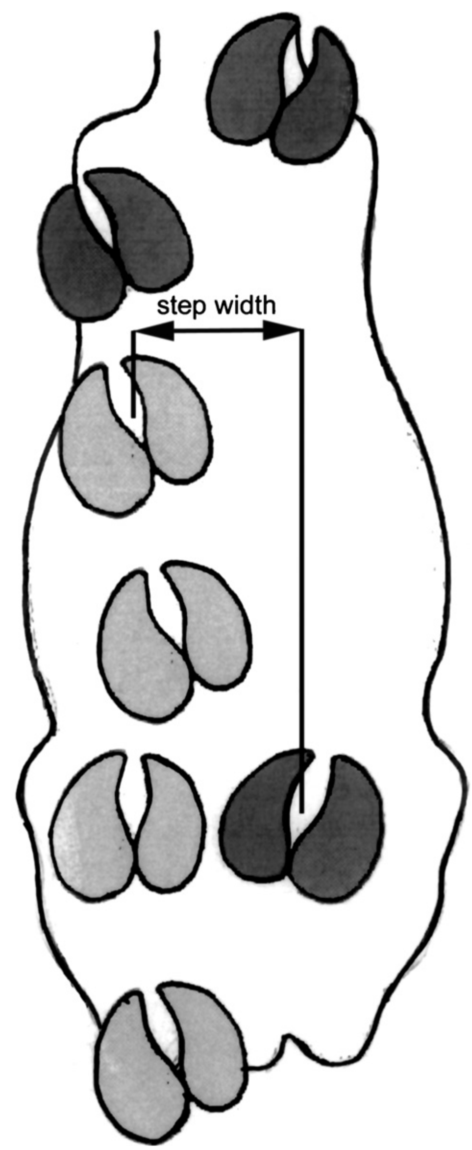

Fig. 1. Schematic representation of a cow's gait showing the step width (two-arrowed line) as viewed from above.

speed camera (Motion Scope PCI 1000S, Redlake Imaging Corporation), with a resolution of 320 × 280 pixels, connected to a personal computer was used. Three spotlights (220 V, 1000 W, 300 Hz) were focused on the foot being studied. A film sequence lasted 4 s and included three complete stride cycles. Given a frame rate of 500 frames/s, this amounted to 2000 frames/s. Five defined camera positions were used according to Meyer et al. (2007): forelimbs (1) were filmed from the front, and hindlimbs (2) from the back. The left fore (3) and hind (4) limb were filmed from the left side and the left hindlimb (5) was filmed obliquely from the front at a 45° angle. For each camera position, film sequences were taken in succession as only one high-speed camera was available.

The film sequences were visually assessed using the software program MIDAS Player (Redlake Imaging Corporation). This allowed the assessment of film sequences frame by frame. For each frame, the time (relative to the 4 s sequence) and the corresponding frame number were available, which allowed temporal gait characteristics, such as the duration of the stance phase, to be calculated.

In the front and rear views, the pattern of first ground contact (i.e., lateral claw, both claws simultaneously, or medial claw) was evaluated visually. In the side and oblique views, the order of the ground contact of the different parts of the lateral claws (heel, wall and toe area) was evaluated. The time between first contact of the lateral and medial claws could be determined only for the hindlimbs because both heels could be assessed accurately only on caudal view. In one cow, the gait on grass and on asphalt was recorded with a hand-held video camera and slow motion sequences were compared.

The experiment was approved by the veterinary authorities of the canton of Zurich (Approval No. 41/2005). After the study, all the cows were returned in good health to their owners.

Results

All cows became accustomed to the treadmill without problems and had adopted a uniform gait pattern by the time the high speed cinematography recordings were done. The step width could be determined in only 10/12 cows because two did not tolerate the angular encoding devices on their pasterns. There were no differences in gait patterns among the individual cows or between the breeds. The stride frequency was 43/min (SD = 1.8) at an average treadmill speed of 1.2 m/s (SD = 0.05). During protraction, the limb was advanced in a slight S-curve around the weight-bearing contralateral limb (Fig. 2). The front and hind feet contacted the ground with a slight outward rotation so that the interdigital cleft pointed slightly laterally. Immediately before landing, the tips of the claws pointed slightly dorsally and the soles craniolaterally (Fig. 3), so that the heels of the lateral claws were closest to the ground. Although the feet contacted the ground near the median of the body, the step width was wide enough to allow complete visual assessment of the digits. The step width 1 was 15 cm in the hindlimbs and 10 cm in the forelimbs (Table 1).

In 10/12 cows, the lateral claw of the forelimb contacted the ground first; in the other two cows, the lateral and medial claws contacted the ground simultaneously. In the hindlimbs, the lateral claw contacted the ground first in all cows (Fig. 4a). This was best seen in the front view of the forelimbs and in the oblique view of the hindlimbs. In the forelimb and hindlimbs, the feet underwent a tipping movement from caudolateral to craniomedial at ground contact. During the brief moment of initial contact of the lateral claw the medial claw appeared to move uncontrollably before contacting the ground.

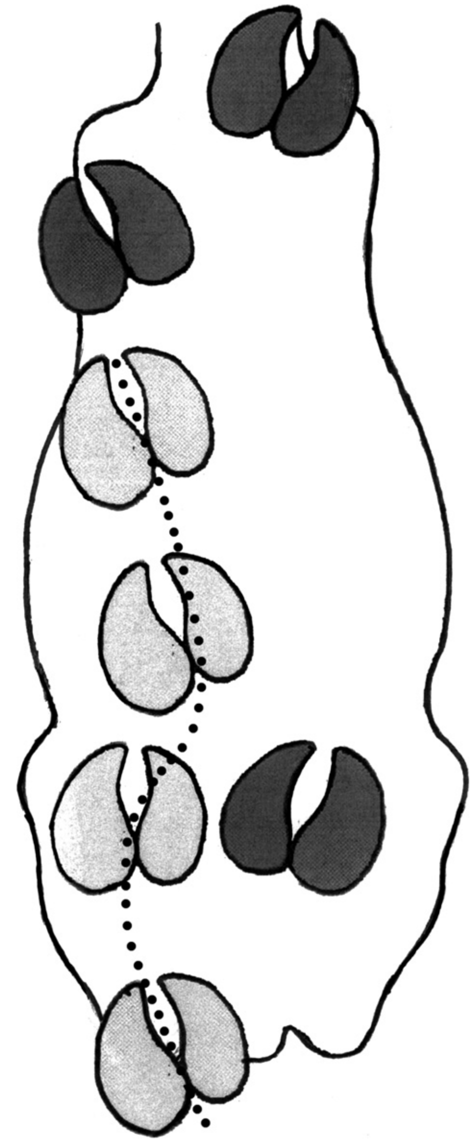

Fig. 2. Schematic representation of a cow showing the sigmoid-shaped advancement (dotted line) of the left hindlimb as viewed from above.

The lateral heel was the first part of the claw to make contact with the ground in all of the hindlimbs (Fig. 4b) and in nine forelimbs. In two cows, the forelimb contacted the ground with the tip of the claw and in one cow with the abaxial weight-bearing border of the claw. The heel of the medial claw touched the ground an average of 25.7 ms (SD = 16.6 ms) after the heel of the lateral claw (Table 2). During initial ground contact and deceleration of the lateral claw, compression of the tissues immediately proximal to the coronary band was evident (Fig. 5). The entire medial claw contacted the ground an average of 37.9 ms (SD = 20.4 ms) after the heel of the lateral claw in the forelimb and 35.5 ms (SD = 10.2 ms) in the hindlimb.

Fig. 3. The claws of the left hindlimb of cow Number 2 at landing. The heel of the lateral claw is closest to the ground and contacts the ground first. The tips of the claws point slightly dorsally and the interdigital cleft and the soles craniolaterally.

Table 1
Step width (mean and standard deviation SD) in lactating cows compared to heifers

Parameter	Cows ($n = 10$)		Heifers ($n = 9$)[a]	
	Forelimb	Hindlimb	Forelimb	Hindlimb
Treadmill velocity (m/s)	1.2 (SD = 0.05)		1.3 (SD = 0.04)	
Step width at heel strike (step width 1)	10 cm (SD = 0.03)	15 cm (SD = 0.06)	12 cm (SD = 0.02)	6 cm (SD = 0.03)
Step width end of stance (cm)	9 cm (SD = 0.03)	17 cm (SD = 0.05)	9 cm (SD = 0.02)	9 cm (SD = (0.06)

[a] Meyer (2006).

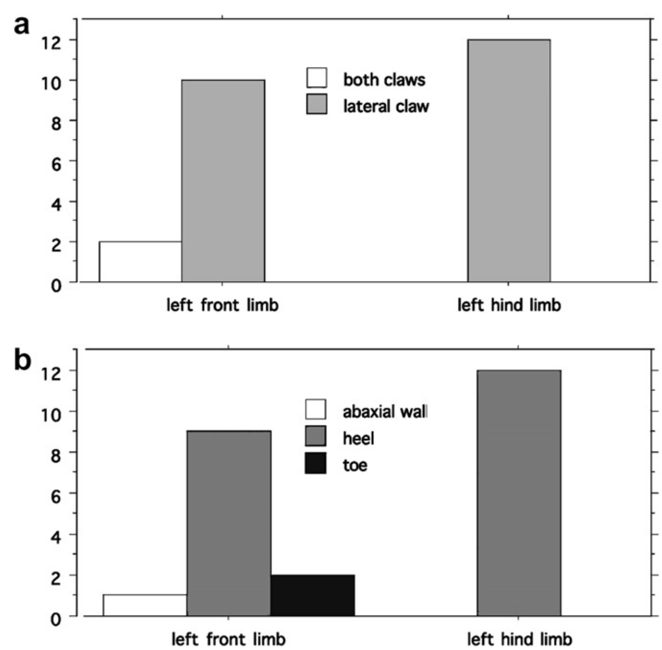

Fig. 4. (a) Bar graph showing which claw contacts the ground first in the front and hindlimbs. The lateral claw almost always contacted the ground first. (b) Bar graph showing that the claw region that contacted the ground first was the heel in the majority of the forelimbs and in all the hindlimbs.

Landing occurred in the following order: heel of the lateral claw, tip of the lateral claw, heel of the medial claw and tip of the medial claw. During the supporting limb phase, the length axis of the cannon bone and the digits shifted from lateral to medial (Fig. 5). In the forelimb, the tip of the medial claw contacted the ground an average of 29.5 ms (SD = 19.3 ms) after the tip of the lateral claw. In the hindlimb, this time lag was an average of 27.7 ms (SD = 9.8 ms). In the forelimbs the differences in ground contact between claws had a greater variation than in the hindlimbs. The step width was distinctly larger in the hindlimbs than in the forelimbs (Table 1). In the forelimbs, the step width was slightly larger at heel strike than at push-off. In direct contrast, the step width in the hindlimbs was slightly larger during push-off. This indicated that during

Table 2
Time lapse (ms) between landing of different parts of the claws of the front and hindlimbs of lactating cows

	Forelimbs			Hindlimbs		
	Mean	Min	Max	Mean	Min	Max
Lateral heel to lateral tip	4.9 (SD = 8.8)	−12.7	16.7	11.0 (SD = 5.5)	3.3	26.0
Lateral tip to medial tip	29.5 (SD = 19.3)	2.7	66.7	27.7 (SD = 9.8)	15.3	48.0
Initial contact to complete ground contact of both claws	37.9 (SD = 20.4)	4.7	68	35.5 (SD = 10.2)	15.3	48.0

the push off phase the front feet shifted slightly inwards, while the hind feet rotated slightly outwards.

Although less detailed than high-speed cinematography, the video recording of a cow walking on a hard surface showed no major differences in gait or claw ground contact compared with the treadmill study. When viewed in slow motion, the lateral claw contacted the ground first, followed by a tipping movement of the foot from lateral to medial. On grass, both claws sank into the ground, the lateral claw first, immediately followed by the medial claw. Thus, in contrast to walking on asphalt or on the treadmill, the claws did not land hard and did not appear to come to a sudden halt when contacting the grass. There was a smooth transition from the first ground contact of the lateral claw to the beginning of weight-bearing by the medial claw. In particular, the brief period of the apparently involuntary movement of the medial claw just before ground contact did not occur. In the cow walking on grass, the interdigital space appeared narrower than in cows on the treadmill.

Discussion

The cows of this study adapted to the treadmill within two or three training sessions, which is similar to a previous study on heifers (Meyer, 2006; Meyer et al., 2007). Because the cows originated from tie-stall operations, they were used to being handled. The speed of the treadmill (1.2 m/s) was slightly slower than that used for the heifers (1.3–1.4 m/s; Meyer et al., 2007). This indicates either that the treadmill velocity chosen might have been too fast for the heifers, or, since the speed was set individually for each animal in both studies, that mature cows prefer to walk more slowly than young heifers.

Gait analysis was done 2–7 h after milking so that there was no udder distension. The step width in lactating cows was smaller in the forelimbs and distinctly larger in the hindlimbs. This was in contrast to heifers, which had wider steps in the front and narrower steps in the hindlimbs (Meyer, 2006). Therefore we assume that the udder forced the hindlimbs further apart. This facilitated filming the hindlimbs from the rear, whereas in heifers, filming from the rear was not possible because the hindlimbs blocked each other from view.

As for to the observations made in heifers (Meyer et al., 2007), it was also evident in cows that the lateral claw made contact with the ground before the medial claw in both the forelimbs and hindlimbs. Landing ‘heel first’ was aided by the oblique outward direction of the limb axis and sole (Fig. 3). The main difference in the gait pattern between

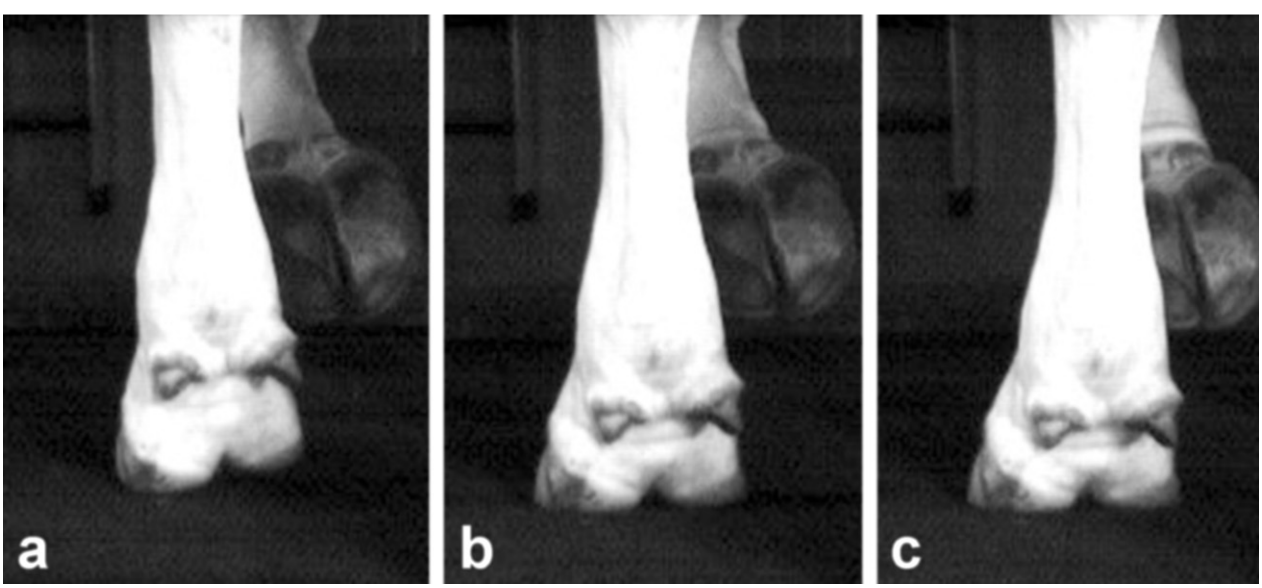

Fig. 5. The shift of the length axis of the cannon bone and the digits from lateral to medial (‘tipping’ or ‘rolling’ movement) during heel strike, deceleration phase and midstance of the left hindlimb of a 6-year old Swiss Braunvieh cow. (a) The lateral claw contacts the ground first (heel strike), the interdigital cleft is turned slightly laterally and the medial claw is still suspended. The length axis of the cannon bone is directed slightly laterally. (b) The medial claw contacts the ground in the deceleration phase, and the cannon bone axis is vertical. (c) Both claws bear weight in midstance, and the cannon bone axis has shifted medially.

heifers (Meyer, 2006; Meyer et al., 2007) and lactating cows was a greater step width in the latter. It may be speculated that the horizontal GRF and the shear forces increase when the lateral claw lands further from the median (step width; Fig. 1 and Table 1). In addition, the time lag between the ground contact of the lateral heel and complete contact of the medial claws of the hindlimbs was longer in the cows of this study (35.5 ms; Table 2) compared to the heifers of the previous study (24.0 ms; Meyer, 2006). A larger time lag may account for an increased load of the lateral claws in lactating cows. In the study of Meyer (2006), however, the start and end of the time lag was less clearly defined than in our study (Table 2). Also, the time lag in the forelimbs compared to the hindlimbs was much shorter in the heifers (14.0 ms; Meyer, 2006), but slightly longer in the cows (37.9 ms; Table 2).

During heel strike and braking, compression of the tissues immediately proximal to the coronary band of the lateral claw was observed (Fig. 5b). This was interpreted as a visual correlative of compressed internal structures. During the milliseconds when the lateral claw first contacted the ground, the entire impact forces acted solely on that claw. Impact forces typically occur 20–30 ms after initial ground contact (Nigg et al., 1988) and are directly related to the properties of the ground surface (Franck and De Belie, 2006). Because of the time lapse between the lateral and medial claw in all phases of the stance phase, the lateral claw incurred a higher vGRF than the medial claw. This pattern was also evident in pressure and force studies carried out by van der Tol et al. (2003).

What is not clear, however, is why the lateral claws of the forelimbs, like those of the hindlimbs, do not noticeably suffer from increased stress considering that the ground contact patterns were similar. It has been stated that changes in limb loading in pregnancy may predispose cows to foot problems; interestingly, the load distribution between front and hind feet did not change in heifers during late pregnancy (Scott, 1988). Other studies (van der Tol et al., 2003; Carvalho et al., 2005) found that the forelimbs of lactating cows bore substantially more weight than the hindlimbs.

In the forelimbs, there is no obvious predisposition of the medial or lateral claw to disease. While sole ulcers occur more often in the medial claws of the forelimbs (Toussaint Raven, 1989), indicating increased weight-bearing, vertical fissures occur almost exclusively in the lateral claws of the forelimbs (Petrie et al., 1998). There are also studies that reported that the lateral claws of the forelimbs were just as prone to disease as the medial claws (Distl and Schmid, 1993; Leach et al., 1998). According to van der Tol et al. (2002, 2003), the vGRF is distributed evenly between the claws of the forelimbs, whereas Carvalho et al. (2005) reported that the peak pressures at the deceleration phase were concentrated on the lateral sole and heel regions also in the front legs. The latter findings are supported by the results of our study. Possibly the effect of the various ground reaction forces is mitigated via a cushioning by the musculotendinous attachment of the forelimbs to the trunk, as opposed to the bony attachment in the hindlimbs (Toussaint Raven, 1989).

In spite of differences in the timing of the placement of the lateral and medial claws, the overall gait pattern observed in the cows of this study was very similar to that of heifers (Meyer et al., 2007) and did not differ between the two breeds used here. However, the numbers of animals examined were small, the milk production of the cows used in this study was not very high and no cow had an extremely large udder. Cows with a very large udder may have a gait pattern that deviates from that seen in our study. To the authors' knowledge, there has been no proven association between udder size and claw disease. Further studies should evaluate gait patterns in cows during the weeks before and after parturition and to examine possible changes in relation to hormonal and metabolic events (Tarlton et al., 2002; Knott et al., 2007).

Because the video recordings of the cow walking on grass were less accurate in detail, the observations must be interpreted carefully. Nevertheless they revealed some important differences compared with walking on a hard surface. When walking on grass, the cow that we studied had an easy and relaxed gait. Presumably, the various ground reaction forces during heel strike and maximum braking on a deformable surface were considerably smaller. In contrast to a hard surface, on soft ground the lateral claw sinks into the ground and the medial claw is likely to contribute to weight-bearing from the beginning of stance. An earlier, preliminary study on dynamic stress of the claws of a heifer supports this assumption (Seebacher et al., 1980) by showing that on a soft gravel surface, the medial claw of the forelimb bore more weight than the lateral claw, whereas on concrete and slatted floors, this pattern of weight-bearing was reversed. Furthermore, on grass the vGRF are expected to be evenly distributed over the entire sole, so that pressure maxima and pressure points (Distl et al., 1990; van der Tol et al., 2003; Zeiner et al., 2007) should be greatly reduced. It seems logical to assume that the gait pattern of cattle evolved on soft surfaces and that problems are likely to occur when cattle are housed permanently on hard surfaces.

Cattle prefer to walk on soft surfaces, and it has been shown that certain claw lesions improve when the animals are turned out on pasture (Flower et al., 2007; Hernandez-Mendo et al., 2007). Our high-speed recordings emphasised the stress the lateral claw underwent when it contacted a hard surface. Housing on hard surfaces alone does not completely explain why sole ulcers and other claw diseases first occur in young cows and are rare in young heifers and calves. The occurrence of claw disease around first calving may be related to alterations of the connective tissues caused by a combination of metabolic changes around the time of calving and hard flooring (Knott et al., 2007). The gait pattern observed in our study offers an explanation of why the lateral claw of the hindlimb is predisposed to disease. More detailed biomechanical studies are needed to explain why there is no predisposition of the lateral claw in the forelimbs despite similar gait patterns.

Conclusions

Lactating cows of two different breeds had gait and claw-ground contact patterns similar to those of heifers. In the vast majority of cows, the lateral claw contacted the ground before the medial claw in both the front and hindlimbs. Compared with heifers, lactating cows had a larger step width in the hindlimbs, which might alter the ground reaction forces of the lateral claws at heel strike. The results of this study suggest again that soft surfaces should be provided for cattle to prevent mechanical injury to the (lateral) claws.

Conflicts of interest

None of the authors of this paper has a financial or personal relationship with other people or organisations that could inappropriately influence or bias the content of the paper.

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